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(54) OFDM transmitter and receiver.

(57) A signal transmitting apparatus using orthogonal frequency division multiplexing includes an inverse fast Fourier transform circuit for converting a digital information signal into a first multi-value QAM modulation signal. A guard interval setting circuit is operative for periodically generating a guard interval signal equal to a time segment of the first multi-value QAM modulation signal, and inserting the guard interval signal into the first multi-value QAM modulation signal to convert the first multi-value QAM modulation signal into a second multi-value QAM modulation signal. A clock signal generating circuit is operative for generating a first clock signal which drives the inverse fast Fourier transform circuit, and generating a second clock signal which drive the guard interval setting circuit. The inverse fast Fourier transform circuit is operative for generating a pilot signal which corresponds to a given-order carrier, and adding the pilot signal to the first multi-value QAM modulation signal. The pilot signal has a predetermined frequency and an angle modulation component which remains constant over a plurality of symbol periods. The pilot signal corresponding to a given integer times its wavelength is present in a guard interval occupied by the guard interval signal in the second multi-value QAM modulation signal. The pilot signal is continuously present over the guard interval and another interval.

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BACKGROUND OF THE INVENTION

This invention relates to a signal transmitting apparatus using orthogonal frequency division multiplexing. This invention also relates to a signal receiving apparatus using orthogonal frequency division multiplexing.

Orthogonal frequency division multiplexing (OFDM) uses multiple carriers which are modulated in accordance with information to be transmitted. The carriers have an orthogonal relationship with each other. Data transmission based on OFDM is executed symbol by symbol. Each OFDM transmission symbol interval is composed of a guard interval and an effective symbol interval. The guard interval is used for reducing multipath effects. The effective symbol interval is used for transmitting data.

In an OFDM receiver side, the reproduction of carriers without time-base variations in phases is generally required to accurately recover transmitted data. Various factors hinder such good reproduction.

SUMMARY OF THE INVENTION

It is a first object of this invention to provide an improved signal transmitting apparatus using orthogonal frequency division multiplexing.

It is a second object of this invention to provide an improved signal receiving apparatus using orthogonal frequency division multiplexing.

A first aspect of this invention provides a signal transmitting apparatus using orthogonal frequency division multiplexing which comprises an inverse fast Fourier transform circuit for converting a digital information signal into a first multi-value QAM modulation signal; a guard interval setting circuit for periodically generating a guard Interval signal equal to a time segment of the first multi-value QAM modulation signal, and Inserting the guard interval signal into the first multi-value QAM modulation signal to convert the first multi-value QAM modulation signal into a second multi-value QAM modulation signal; and a clock signal generating circuit for generating a first clock signal which drives the Inverse fast Fourier transform circuit, and generating a second clock signal which drive the guard interval setting circuit; wherein the inverse fast Fourier transform circuit comprises means for generating a pilot signal which corresponds to a given-order carrier, and adding the pilot signal to the first multi-value QAM modulation signal, wherein the pilot signal has a predetermined frequency and an angle modulation component which remains constant over a plurality of symbol periods, wherein the pilot signal corresponding to a given integer times its wavelength is present in a guard interval occupied by the guard interval signal in the second multi-value QAM modulation signal, and wherein the pilot signal is continuously present over the guard interval and another interval.

It is preferable that the first clock signal and the second clock signal are the same.

It Is preferable that a ratio between the frequency of the pilot signal and a frequency of the first clock signal is equal to a ratio between predetermined integers.

A second aspect of this invention provides a signal receiving apparatus using orthogonal frequency division multiplexing which comprises first means for reproducing a pilot signal from a multi-value QAM modulation signal by angle demodulation; second means for converting a frequency of the reproduced pilot signal to change the reproduced pilot signal into a clock signal; and a fast Fourier transform circuit for converting the multi-value QAM modulation signal into a digital information signal; wherein the fast Fourier transform circuit is driven by the clock signal generated by the second means.

A third aspect of this invention provides a signal transmitting apparatus using orthogonal frequency division multiplexing which comprises an inverse fast Fourier transform circuit for converting a digital information signal into a first multi-value QAM modulation signal; a guard interval setting circuit for periodically generating a guard interval signal equal to a time segment of the first multi-value QAM modulation signal, and Inserting the guard Interval signal into the first multi-value QAM modulation signal to convert the first multi-value QAM modulation signal into a second multi-value QAM modulation signal; and a clock signal generating circuit for generating a first clock signal which drives the inverse fast Fourier transform circuit, and generating a second clock signal which drive the guard interval setting circuit; wherein the inverse fast Fourier transform circuit comprises means for setting a given-order carrier as a reference carrier, wherein the given-order carrier corresponding to a given integer times approximately its half wavelength is present in a guard interval occupied by the guard interval signal in the second multi-value QAM modulation signal, and wherein the inverse fast Fourier transform circuit comprises means for changing a phase of the reference carrier for every symbol interval by an amount corresponding to a given odd number times its quarter wavelength.

It Is preferable that the first multi-value QAM modulation signal generated by the inverse fast Fourier transform circuit changes between a real part and an imaginary part for every symbol interval.

RF amplifier in the receiving section 80 is fed to a frequency converter 81, being converted into a corresponding IF OFDM signal thereby. The IF OFDM signal has multiple IF orthogonal carriers which are modulated in accordance with transmitted baseband signals respectively. The IF OFDM signal is fed from the frequency converter 81 to a quadrature demodulator 83 and a carrier detecting circuit 90 via an IF amplifying circuit 82.

A local oscillator 89 reproduces a local oscillator signal in response to an output signal of the carrier detecting circuit 90. The local oscillator signal is fed to the quadrature demodulator 83 and a 90° phase shifting circuit 89A. An output signal of the 90° phase shifting circuit 89A is fed to the quadrature demodulator 83. In this way, a pair of reproduced local oscillator signals having a quadrature relation are fed to the quadrature demodulator 83. The IF OFDM signal is demodulated by the quadrature demodulator 83 into baseband signals corresponding to a real part and an imaginary part (an I signal and a Q signal).

Output signals from the quadrature demodulator 83 are fed via an LPF 84 to an A/D converter 85, being changed into corresponding digital signals thereby. One of the output signals from the quadrature demodulator 83 is fed to a sync signal generating circuit 91. The circuit 91 reproduces and generates sync signals or clock signals in response to the output signal of the quadrature demodulator 83.

Output signals from the A/D converter 85 are fed via a guard interval circuit 86 to an FFT QAM (fast Fourier transform, quadrature amplitude modulation) decoding circuit 87. The circuit 87 subjects output signals of the guard interval circuit 86 to processing which corresponds to complex Fourier transform. According to the complex Fourier transform processing, the circuit 87 derives the levels of baseband carriers in the real-part signal and the imaginary-part signal outputted from the guard interval circuit 86. Thus, the transmitted digital information is recovered.

Output signals of the FFT QAM decoding circuit 87 are fed to a parallel-to-serial (P/S) conversion circuit 88. An output signal of the P/S conversion circuit 88 is fed to an external device (not shown) as an output signal of the prior-art OFDM signal receiver.

The sync signals and the clock signals are fed from the sync signal generating circuit 91 to the A/D converter 85, the guard interval circuit 86, the FFT QAM decoding circuit 87, and the P/S conversion circuit 88 as operation timing control signals respectively.

In the prior-art OFDM signal transmitter of Fig. 1 and the prior-art OFDM signal receiver of Fig. 2, transmitted data can be accurately recovered by the receiver when the frequencies of the carriers in the receiver are exactly equal to the frequencies of the carriers in the transmitter. A difference in frequency between the output signal of a local oscillator in the frequency converter 76 in the transmitter and the output signal of a local oscillator in the frequency converter 81 in the receiver causes a disagreement between the carriers in the transmitter and the carriers in the receiver. In addition, a difference in frequency between the output signal of the local oscillator 78 in the transmitter and the output signal of the local oscillator 89 in the receiver causes a disagreement between the carriers in the transmitter and the carriers in the receiver. Such a disagreement results in an increased symbol error rate related to data recovered by the receiver.

In the prior-art OFDM signal transmitter of Fig. 1 and the prior-art OFDM signal receiver of Fig. 2, transmitted data can be accurately recovered by the receiver when the clock signal fed to the IFFT circuit 71 in the transmitter accurately corresponds to the clock signal fed to the FFT QAM decoding circuit 87 in the receiver. A disagreement between the clock signal fed to the IFFT circuit 71 and the clock signal fed to the FFT QAM decoding circuit 87 results in an increased symbol error rate related to data recovered by the receiver.

First Embodiment

Fig. 3 shows a signal transmitting apparatus using orthogonal frequency division multiplexing (OFDM) according to a first embodiment of this invention. Digital data transmitted by the signal transmitting apparatus of Fig. 3 agrees with, for example, a compressed audio signal and a compressed video signal.

OFDM uses multiple carriers having an orthogonal relationship with each other. In OFDM data transmission, independent digital information pieces are transmitted by using multiple carriers respectively. Since the carriers are orthogonal with each other, the levels of the spectrums of carriers neighboring a given carrier are nullified at a point corresponding to the frequency of the given carrier.

An IFFT (inverse fast Fourier transform) circuit is used to enable the generation of a set of multiple orthogonal carriers. A baseband OFDM signal can be generated by executing inverse discrete Fourier transform (inverse DFT) using N complex numbers during a time interval T. Points of the inverse DFT correspond to modulation signal outputs respectively.

Basic specifications of the signal transmitting apparatus of Fig. 3 are as follows. The central carrier frequency in an RF band is equal to 100 MHz. The number of carriers for data transmission

nally-stored portions of the output signals of the IFFT and pilot signal generating circuit 3 are read out from the RAM 4A so that signals occupying a guard interval "gi" are generated. Subsequently, the output signals of the IFFT and pilot signal generating circuit 3 are read out from the RAM 4A in a sequence starting from the firstly-stored portions thereof so that signals occupying an effective symbol interval "ts" are generated.

The previously-indicated Nyquist frequency information can be transmitted by using not only an effective symbol interval but also a guard interval. Regarding the Nyquist frequency information, to maintain the continuity with preceding and following IFFT window interval signals, it is preferable that the pilot signal corresponding to one wavelength multiplied by a given integer is present in a guard interval. In this case, the pilot signal in a symbol interval is continuously present over a guard interval and an effective symbol interval. Thus, an actually-transmitted pilot signal, that is, the pilot signal up-converted into a transmission RF range, has a monochromatic frequency spectrum (a single-line frequency spectrum).

In this embodiment, the pilot signal has the Nyquist frequency. It should be noted that the frequency of the pilot signal may differ from the Nyquist frequency as long as there is a relation in frequency between the pilot signal and the sample position signal which is denoted by a simple ratio between integers. The pilot signal may use transmitted highest-frequency information.

In the case of IFFT having a period M, a pilot signal is located at a frequency position equal to a half of a Nyquist frequency corresponding to each of a period M/4 and a period 3M/4. In addition, carriers transmitted by OFDM use those corresponding to first to M/4-th output signals from the IFFT, and those corresponding to 3M/4-th to M-th output signals from the IFFT. Thus, it is possible to generate signals equivalent to those generated in the case of $M = 2N$.

Accordingly, a continuous pilot signal can be transmitted by using an effective symbol interval as well as a guard interval. The sample position signal can be generated by recovering the pilot signal and multiplying the frequency of the recovered pilot signal by 4.

In the case where window interval signal information of FFT can be recovered separately, FFT calculations for an OFDM signal can be implemented by combining the window interval signal information and the sample position signal. Thus, in this case, the OFDM signal can be decoded.

A description will now be given of a symbol interval "ta" related to the guard interval setting circuit 4. In the case where the used frequency band is equal to 99 kHz and the period N is given as $N = 256$, an effective symbol frequency "fs" and an effective symbol period "ts" are expressed as follows.

$$fs = 99{,}000/256 = 387 \text{ Hz}$$
$$ts = 1/fs = 2{,}586\ \mu\text{sec}$$

When the guard interval "gi" for removing multipath effects is set to six times the sample period (six times the reciprocal of the used frequency band), the guard interval "gi" is given as follows.

$$gi = (1/99{,}000) \times 6 = 60.6\ \mu\text{sec}$$

In this case, the symbol interval "ta" and the symbol frequency "fa" are given as follows.

$$ta = ts + gi = 2586 + 60.6 = 2646.6\ \mu\text{sec}$$
$$fa = 1/ta = 378 \text{ Hz}$$

Output signals of the guard interval setting circuit 4 are fed to a D/A converter 5, being converted into corresponding analog signals thereby. The D/A converter 5 outputs the resultant analog signals to a LPF (low pass filter) 6. Only components of the output signals of the D/A converter 5 in a desired frequency band are passed through the LPF 6.

Output signals of the LPF 6 which correspond to the real part and the imaginary part are fed to a quadrature modulator 7 as baseband signals. A local oscillator 9 outputs a given-frequency signal, for example, a 10.7-MHz signal, to the quadrature modulator 7. The frequency of the output signal of the local oscillator 9 corresponds to a given intermediate frequency (IF). The local oscillator 9 also outputs the given-frequency signal to a 90° phase shifting circuit 8. The circuit 8 shifts the phase of the given-frequency signal by 90°, and outputs the phase-shift resultant signal to the quadrature modulator 7. In this way, a pair of given-frequency signals having a quadrature relation are fed to the quadrature modulator 7. In the quadrature modulator 7, the quadrature given-frequency signals are modulated in accordance with the baseband signals outputted from the LPF 6 so that the baseband signals are converted into an IF OFDM (intermediate frequency OFDM) signal. The IF OFDM signal has multiple IF orthogonal carriers which are modulated as indications of the output baseband signals of the LPF 6.

The IF OFDM signal is changed by a frequency converter 11 into an RF OFDM (radio frequency OFDM) signal in a desired frequency band for transmission. The RF OFDM signal has multiple RF orthogonal carriers which are modulated as indications of the output baseband signals of the LPF 6 respectively. The frequency converter 11

respectively.

Output signals from the quadrature demodulator 23 are fed to an LPF 24. Only components of the output signals of the quadrature demodulator 23, which occupy a desired frequency band, are passed through the LPF 24. Output signals of the LPF 24 which have analog forms are fed to an A/D converter 25. The output signals of the LPF 24 are subjected to sampling processes and are converted by the A/D converter 25 into corresponding digital signals.

One of the output signals of the quadrature demodulator 23 is fed to a sample sync signal generating circuit 32. The output signal of the local oscillator 31 is fed to the sample sync signal generating circuit 32. The sample sync signal generating circuit 32 includes a PLL circuit phase-locked with respect to a pilot signal in the output signal of the quadrature demodulator 23. It should be noted that the pilot signal is transmitted as a continuous signal during every symbol interval containing a guard interval. The sample sync signal generating circuit 32 derives pilot signal frequency information, and reproduces the pilot signal.

In a transmitter side, the frequency of the pilot signal is set to correspond to a given ratio between integers with respect to the frequency of the sample clock signal. The sample sync signal generating circuit 32 includes a frequency multiplier operating on the reproduced pilot signal at a multiplying factor corresponding to the above-indicated frequency ratio. A sample clock signal (a clock sync signal) is recovered through the frequency multiplication.

The output signals of the A/D converter 25 are fed to a guard interval processing circuit 26. The guard interval processing circuit 26 extracts time-portions of the output signals of the A/D converter 25 which occupy every effective symbol interval. Output signals of the guard interval processing circuit 26 are fed to an FFT QAM (fast Fourier transform, quadrature amplitude modulation) decoding circuit 27.

A symbol sync signal generating circuit 33 connected to the sample sync signal generating circuit 32 detects a symbol interval in response to the sample clock signal, and generates a symbol sync signal related to the detected symbol interval.

The FFT QAM decoding circuit 27 receives the clock sync signal and the symbol sync signal from the sample sync signal generating circuit 32 and the symbol sync signal generating circuit 33. In response to the clock sync signal and the sample sync signal, the circuit 27 subjects the output signals of the guard interval processing circuit 26 to processing which corresponds to complex Fourier transform. According to the complex Fourier transform processing, the circuit 27 derives the levels of baseband carriers in the real-part signal and the imaginary-part signal outputted from the guard interval processing circuit 26. In the FFT QAM decoding circuit 27, the derived real-part levels and the derived imaginary-part levels are compared with reference demodulation output levels so that the states of transmitted digital signals are determined. In this way, the transmitted digital information is recovered.

Output signals of the FFT QAM decoding circuit 27 which correspond to the recovered digital signals are fed to a parallel-to-serial (P/S) conversion circuit 28. The output signals of the FFT QAM decoding circuit 27 are rearranged and combined by the P/S conversion circuit 28 into a serial-form digital signal. The serial-form digital signal is transmitted from the P/S conversion circuit 28 to an external device (not shown) via an output terminal 34.

The sample sync signal generating circuit 32 and the symbol sync signal generating circuit 33 produce sync signals and clock signals in response to the output signal of the quadrature demodulator 23 and the output signal of the local oscillator 31, and feed the produced sync signals and the produced clock signals to the A/D converter 25, the guard interval processing circuit 26, the FFT QAM decoding circuit 27, and the P/S conversion circuit 28 as operation timing control signals.

The pilot signal in the output signal of the quadrature demodulator 23 is continuous, and is free from jitter components. Therefore, the pilot signal is recovered without jitter, and the sample clock signal is accurately reproduced in response to the recovered pilot signal. The clock signal fed to the FFT QAM decoding circuit 27 in the receiver side accurately corresponds to the clock signal fed to the the IFFT and pilot signal generating circuit 3 in the transmitter side. Thus, the FFT process in the receiver side can be exactly inverse with the IFFT process in the transmitter side so that the transmitted data can be accurately recovered in the receiver side.

Third Embodiment

Fig. 6 shows a portion of a signal receiving apparatus using orthogonal frequency division multiplexing (OFDM) according to a third embodiment of this invention. The signal receiving apparatus of Fig. 6 is similar to the signal receiving apparatus of Fig. 5 except for design changes indicated later.

The signal receiving apparatus of Fig. 6 includes the following circuits in place of the quadrature demodulator 23, the carrier detecting circuit 29, the 90° phase shifting circuit 30, the local oscillator 31, and the sample sync signal generating circuit 32 of Fig. 5.

and the frequency divider 50 is designed to provide a frequency division factor of 1/4.

Fifth Embodiment

Fig. 7 shows a signal transmitting apparatus using orthogonal frequency division multiplexing (OFDM) according to a fifth embodiment of this invention. Digital data transmitted by the signal transmitting apparatus of Fig. 7 agrees with, for example, a compressed audio signal and a compressed video signal.

OFDM uses multiple carriers having an orthogonal relationship with each other. In OFDM data transmission, independent digital information pieces are transmitted by using multiple carriers respectively. Since the carriers are orthogonal with each other, the levels of the spectrums of carriers neighboring a given carrier are nullified at a point corresponding to the frequency of the given carrier.

An IFFT (inverse fast Fourier transform) circuit is used to enable the generation of a set of multiple orthogonal carriers. A baseband OFDM signal can be generated by executing inverse discrete Fourier transform (inverse DFT) using N complex numbers during a time interval T. Points of the inverse DFT correspond to modulation signal outputs respectively.

Basic specifications of the signal transmitting apparatus of Fig. 7 are as follows. The central carrier frequency in an RF band is equal to 100 MHz. The number of carriers for data transmission is equal to 248. The modulation is of 256-QAM OFDM type. The number of used carriers is equal to 257. The transmission band width is equal to 100 kHz. The used band width is equal to 99 kHz. The transmission data rate is equal to 750 kbps. The guard interval is equal to 60.6 µsec.

A description will now be given of arrangement of the carriers. In an IF band, a carrier having a frequency equal to a central IF frequency (that is, 10.7 MHz) is referred to as a 0-th carrier. Carriers extending in a frequency upper side (a right-hand side) of the 0-th carrier are sequentially referred to as a 1-st carrier, a 2-nd carrier, a 3-rd carrier, ···, and a 128-th carrier respectively. Carriers extending in a frequency lower side (a left-hand side) of the 0-th carrier are sequentially referred to as a -1-st carrier, a -2-nd carrier, a -3-rd carrier, ···, and a -128-th carrier respectively. In this way, the different order numbers are sequentially given to the carriers respectively.

The carriers are assigned to functions (roles) as follows:

The 0-th carrier is used as a non-modulated carrier providing a reference for amplitudes and phases of the other carriers;

The 1-st carrier is used to transmit system mode information;

The 2-nd carrier is used to transmit Information to be transmitted with a positive calibration carrier;

The 21-st carrier is used to periodically transmit a sequence of four symbols representing a reference angle level, a reference amplitude level, and a carrier absence;

The 128-th carrier is used as a carrier having a positive maximum frequency;

The -1-st carrier is used to transmit information of the order numbers of the carriers with which calibration information is transmitted;

The -2-nd carrier Is used to transmit information to be transmitted with a negative calibration carrier;

The -21-st carrier is used to periodically transmit a sequence of four symbols representing a reference angle level, a reference amplitude level, and a carrier absence;

The -128-th carrier is used as a carrier having a negative maximum frequency; and

The other carriers except those designated as calibration information carriers are used to transmit data information signals.

The carriers are defined as follows:

The 0-th carrier agrees with a non-modulated carrier which does not have any angular modulation components;

The 1-st carrier defines a transmission mode; and

The -1-st carrier denotes the positive and negative order numbers of the carriers used as calibration carriers.

Regarding the -1-st carrier, the symbol numbers "0" and "1" are assigned to the carrier order number "X" which indicates the absence of designation of calibration carriers. The symbol numbers "2" and "3" are assigned to the carrier order number "8". The symbol numbers "4" and "5" are assigned to the carrier order number "16". The symbol numbers "6" and "7" are assigned to the carrier order number "24". The symbol numbers "8" and "9" are assigned to the carrier order number "32". Similarly, higher symbol numbers are assigned to higher carrier order numbers.

Symbols following an end signal and a given calibration frame transmitted as mode information bits are sequentially referred to as a 1-st symbol, a 2-nd symbol, a 3-rd symbol, ···, and a 256-th symbol respectively. In this way, the successive numbers (the symbol numbers) are sequentially given to the symbols respectively. The symbol number is initialised or reset to 00 (X'00) at the point of the start of a calibration frame, and is then periodically incremented through a counting process before finally assuming 255 (X'FF). In the case of carrier order numbers "0" and "21", the replacement for carrier calibration is unexecuted.

The symbol number and the calibration carrier has the following relation:

The 248 output signals from the S/P conversion circuit 2 in each of the real part and the imaginary part are fed to a combination 3 of an IFFT (inverse fast Fourier transform) circuit and a pilot signal generating circuit. Also, the 248 output signals from the S/P conversion circuit 2 in each of the real part and the imaginary part are fed to a symbol interval setting circuit 3S.

The symbol interval setting circuit 3S feeds setting signals to the IFFT and pilot signal generating circuit 3 for generating symbol interval information, a QAM demodulating reference amplitude level, and a QAM demodulating reference angle level in response to a common reference carrier while changing the input signals to the IFFT and pilot signal generating circuit 3. The symbol interval setting circuit 3S operates in response to a clock signal fed from a clock signal generating circuit 10.

Regarding the reference carrier, the reference amplitude level and the reference angle level are changed every symbol. For example, the reference carrier corresponding to a given integer times its half wavelength is present in a guard interval. For example, IFFT has a period N of 256, and the guard interval is set to a length corresponding to 6 clock periods. In addition, for example, the ±21-st carriers are used as reference carriers.

The phase difference (variation) of a carrier which is caused by a guard interval depends on the number of clock sample periods composing the guard interval and the frequency order used by IFFT. In the case of IFFT having a period N, the duration of the carrier in the guard interval is given as "$2\pi \times p \times q/N$" where "p" denotes the number of clock periods composing the guard interval, and "q" denotes the frequency order of the carrier used as the reference wave. When $N = 256$ and $p = 6$, the signal with $q = 21$ corresponds to a carrier whose half wavelength is present approximately in the guard interval.

In the case where IFFT has a period N of 256 and the guard interval is set to a length as $p = 4$ clock periods, the 32-nd carrier ($q = 32$) is used to transmit reference signal information.

A further description will now be given in the case where the ±21-st carriers are used as reference carriers. A symbol signal to be transmitted is provided with a number. The symbol signal is transmitted as modulating signals in side bands of the central carrier according to a sequence given by the 2 lower bits of the symbol signal number. Modulating signals related to the 21-st carrier and the -21-st carrier at opposite sides of the central carrier are expressed as follows. When the symbol sequence is "0", the 21-st carrier is set to an "8" amplitude level and a "0" angle level and the -21-st carrier is set to a "0" amplitude level and the "0" angle level. When the symbol sequence is "1", the 21-st carrier is set to the "0" amplitude level and a "-8" angle level and the -21-st carrier is set to the "0" amplitude level and the "0" angle level. When the symbol sequence is "2", the 21-st carrier is set to the "0" amplitude level and the "0" angle level and the -21-st carrier is set to a "-8" amplitude level and the "0" angle level. When the symbol sequence is "3", the 21-st carrier is set to the "0" amplitude level and the "0" angle level and the -21-st carrier is set to the "0" amplitude level and an "8" angle level.

Here, the "0" amplitude level means the absence of amplitude modulation. The "8" amplitude level means the state provided with a positive maximum amplitude modulation degree. The "-8" amplitude level means the state provided with a negative maximum amplitude modulation degree. The "0" angle level means the absence of angle modulation. The "8" angle level means the state provided with a positive maximum angle modulation degree. The "-8" angle level means the state provided with a negative maximum angle modulation degree.

With regard to the setting of levels in the reference carrier for every symbol, one of the positive and negative carriers is subjected to modulation in an amplitude direction or an angle direction. Accordingly, in a receiver side, the levels of reference signals for the inverse quantization of a QAM signal can be known by sequentially recovering the components of the reference signals. In addition, it is possible to know the conditions of a crosstalk between the carriers related to quadrature-modulation signals and the conditions of crosstalks between the positive and negative symmetrical carriers.

The ±21-st carriers serve as side bands with respect to the central carrier. Specifically, in the case where the 21-st carrier is provided with a certain level in a positive amplitude direction (see the previously-indicated symbol sequence "0"), the 21-st carrier is equivalent to a positive side band (an upper side band) among upper and lower side bands which results from amplitude modulation of the central carrier with a signal having a frequency equal to 21 times the symbol frequency. Accordingly, during an effective symbol interval, the side band in question rotates around the central carrier 21 times. During a period corresponding to a guard interval, the side band in question rotates by 1/2.

In the case of the next sequence (see the previously-indicated symbol sequence "1"), the 21-st carrier is equivalent to a positive side band (an upper side band) among upper and lower side bands which results from angle modulation of the central carrier with a negative signal. In the case of the second next sequence (see the previously-indicated symbol sequence "2"), the 21-st carrier

In this embodiment, the pilot signal has the Nyquist frequency. It should be noted that the frequency of the pilot signal may differ from the Nyquist frequency as long as there is a relation in frequency between the pilot signal and the sample position signal which is denoted by a simple ratio between integers. The pilot signal may use transmitted highest-frequency information.

In the case of IFFT having a period M, a pilot signal is located at a frequency position equal to a half of a Nyquist frequency corresponding to each of a period M/4 and a period 3M/4. In addition, carriers transmitted by OFDM use those corresponding to first to M/4-th output signals from the IFFT, and those corresponding to 3M/4-th to M-th output signals from the IFFT. Thus, it is possible to generate signals equivalent to those generated In the case of M = 2N.

Accordingly, a continuous pilot signal can be transmitted by using an effective symbol interval as well as a guard interval. The sample position signal can be generated by recovering the pilot signal and multiplying the frequency of the recovered pilot signal by 4.

In the case where window interval signal information of FFT can be recovered separately, FFT calculations for an OFDM signal can be implemented by combining the window interval signal information and the sample position signal. Thus, in this case, the OFDM signal can be decoded.

A description will now be given of a symbol interval "ta" related to the guard interval setting circuit 4. In the case where the used frequency band is equal to 99 kHz and the period N is given as N = 256, an effective symbol frequency "fs" and an effective symbol period "ts" are expressed as follows.

$$fs = 99{,}000/256 = 387 \text{ Hz}$$
$$ts = 1/fs = 2{,}586\ \mu\text{sec}$$

When the guard interval "gi" for removing multipath effects is set to six times the sample period (six times the reciprocal of the used frequency band), the guard interval "gi" is given as follows.

$$gi = (1/99{,}000) \times 6 = 60.6\ \mu\text{sec}$$

In this case, the symbol interval "ta" and the symbol frequency "fa" are given as follows.

$$ta = ts + gi = 2586 + 60.6 = 2646.6\ \mu\text{sec}$$
$$fa = 1/ta = 378 \text{ Hz}$$

Output signals of the guard interval setting circuit 4 are fed to a D/A converter 5, being converted into corresponding analog signals thereby. The D/A converter 5 operates in response to a clock signal fed from the clock signal generating circuit 10. The D/A converter 5 outputs the resultant analog signals to a LPF (low pass filter) 6. Only components of the output signals of the D/A converter 5 in a desired frequency band are passed through the LPF 6.

Output signals of the LPF 6 which correspond to a real part and an imaginary part (an I component and a Q component) are fed to a quadrature modulator 7 as baseband signals. A local oscillator 9 outputs a given-frequency signal, for example, a 10.7-MHz signal, to the quadrature modulator 7. The frequency of the output signal of the local oscillator 9 agrees with the central intermediate-frequency (IF). The local oscillator 9 outputs the given-frequency signal to a 90° phase shifting circuit 8. The circuit 8 shifts the phase of the given-frequency signal by 90°, and outputs the phase-shift resultant signal to the quadrature modulator 7. In this way, a pair of given-frequency signals having a quadrature relation are fed to the quadrature modulator 7. In the quadrature modulator 7, the quadrature given-frequency signals are modulated in accordance with the baseband signals outputted from the LPF 6 so that the baseband signals are converted into an IF OFDM (intermediate frequency OFDM) signal. The IF OFDM signal has multiple IF orthogonal carriers which are modulated as indications of the output baseband signals of the LPF 6.

The IF OFDM signal is changed by a frequency converter 11 into an RF OFDM (radio frequency OFDM) signal in a desired frequency band for transmission. The RF OFDM signal has multiple RF orthogonal carriers which are modulated as indications of the output baseband signals of the LPF 6. The frequency converter 11 includes a local oscillator and a mixer. In the frequency converter 11, the IF OFDM signal and the output signal of the local oscillator are mixed by the mixer so that the IF OFDM signal is converted into the RF OFDM signal.

The RF OFDM signal is fed to a transmitting section 12 from the frequency converter 11. The transmitting section 12 includes a linear power amplifier and a transmission antenna. The RF OFDM signal is fed via the linear power amplifier to the transmission antenna, being radiated by the transmission antenna into a transmission line (the air).

The output signal of the local oscillator 9 is also fed to the clock signal generating circuit 10. The circuit 10 generates clock signals in response to the output signal of the local oscillator 9 by frequency dividing processes, and outputs the generated clock signals to the S/P conversion circuit 2, the symbol interval setting circuit 3S, the IFFT and pilot signal generating circuit 3, the guard interval setting circuit 4, and the D/A converter 5 as operation timing control signals respectively.

symbol intervals is suited for such a reference carrier provided with phase changes. Accordingly, the ±21-st carriers are used as the reference carriers provided with phase changes. The reference Information in the amplitude direction and the reference information in the angle direction are alternately transmitted, and thus the phase differences (the phase changes) corresponding to an odd number times 90° are given to the ±21-th carriers.

In general, a signal-detecting PLL circuit produces a maximum output with respect to a signal having phase changes corresponding to an odd number times 90°. Therefore, the PLL circuit in the symbol sync signal generating circuit 33A can efficiently detect the reference signal (the phase-change information). Thus, it is possible to accurately reproduce the symbol sync signal.

A signal transmitting apparatus using orthogonal frequency division multiplexing includes an Inverse fast Fourier transform circuit for converting a digital information signal into a first multi-value QAM modulation signal. A guard Interval setting circuit is operative for periodically generating a guard interval signal equal to a time segment of the first multi-value QAM modulation signal, and inserting the guard interval signal into the first multi-value QAM modulation signal to convert the first multi-value QAM modulation signal into a second multi-value QAM modulation signal. A clock signal generating circuit is operative for generating a first clock signal which drives the inverse fast Fourier transform circuit, and generating a second clock signal which drive the guard interval setting circuit. The inverse fast Fourier transform circuit is operative for generating a pilot signal which corresponds to a given-order carrier, and adding the pilot signal to the first multi-value QAM modulation signal. The pilot signal has a predetermined frequency and an angle modulation component which remains constant over a plurality of symbol periods. The pilot signal corresponding to a given integer times its wavelength is present in a guard interval occupied by the guard interval signal in the second multi-value QAM modulation signal. The pilot signal is continuously present over the guard interval and another interval.

Claims

1. A signal transmitting apparatus using orthogonal frequency division multiplexing, comprising:

   an inverse fast Fourier transform circuit for converting a digital information signal into a first multi-value QAM modulation signal;

   a guard interval setting circuit for periodically generating a guard interval signal equal to a time segment of the first multi-value QAM modulation signal, and inserting the guard interval signal into the first multi-value QAM modulation signal to convert the first multi-value QAM modulation signal into a second multi-value QAM modulation signal; and

   a clock signal generating circuit for generating a first clock signal which drives the inverse fast Fourier transform circuit, and generating a second clock signal which drive the guard interval setting circuit;

   wherein the inverse fast Fourier transform circuit comprises means for generating a pilot signal which corresponds to a given-order carrier, and adding the pilot signal to the first multi-value QAM modulation signal, wherein the pilot signal has a predetermined frequency and an angle modulation component which remains constant over a plurality of symbol periods, wherein the pilot signal corresponding to a given integer times its wavelength is present in a guard interval occupied by the guard interval signal in the second multi-value QAM modulation signal, and wherein the pilot signal is continuously present over the guard interval and another interval.

2. The signal transmitting apparatus of claim 1, wherein the first clock signal and the second clock signal are the same.

3. The signal transmitting apparatus of claim 1, wherein a ratio between the frequency of the pilot signal and a frequency of the first clock signal is equal to a ratio between predetermined integers.

4. A signal receiving apparatus using orthogonal frequency division multiplexing, comprising:

   first means for reproducing a pilot signal from a multi-value QAM modulation signal by angle demodulation;

   second means for converting a frequency of the reproduced pilot signal to change the reproduced pilot signal into a clock signal; and

   a fast Fourier transform circuit for converting the multi-value QAM modulation signal into a digital information signal;

   wherein the fast Fourier transform circuit Is driven by the clock signal generated by the second means.

5. A signal transmitting apparatus using orthogonal frequency division multiplexing, comprising:

   an inverse fast Fourier transform circuit for converting a digital information signal into a first multi-value QAM modulation signal;

   a guard interval setting circuit for periodi-

FIG. 1 PRIOR ART

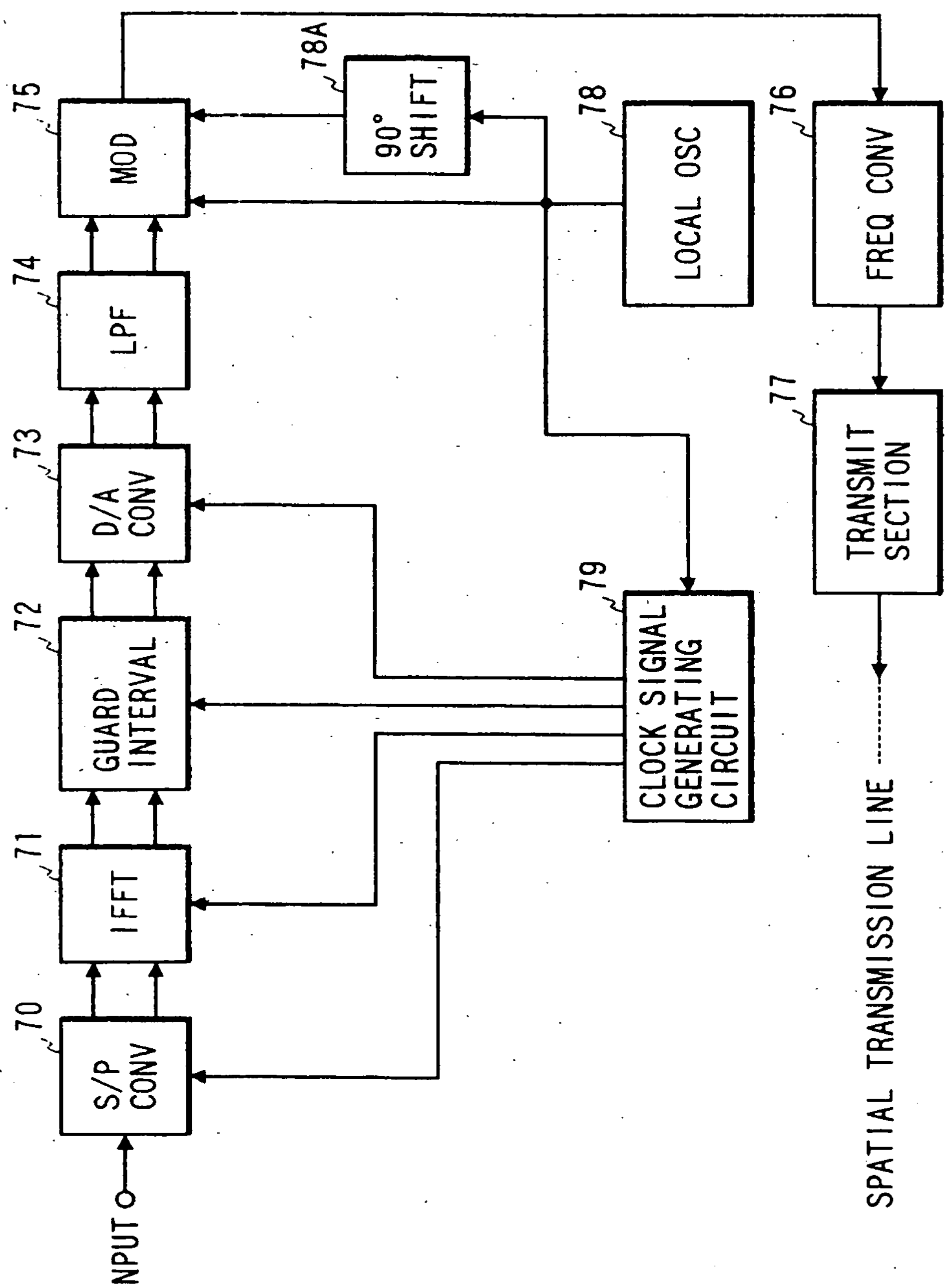
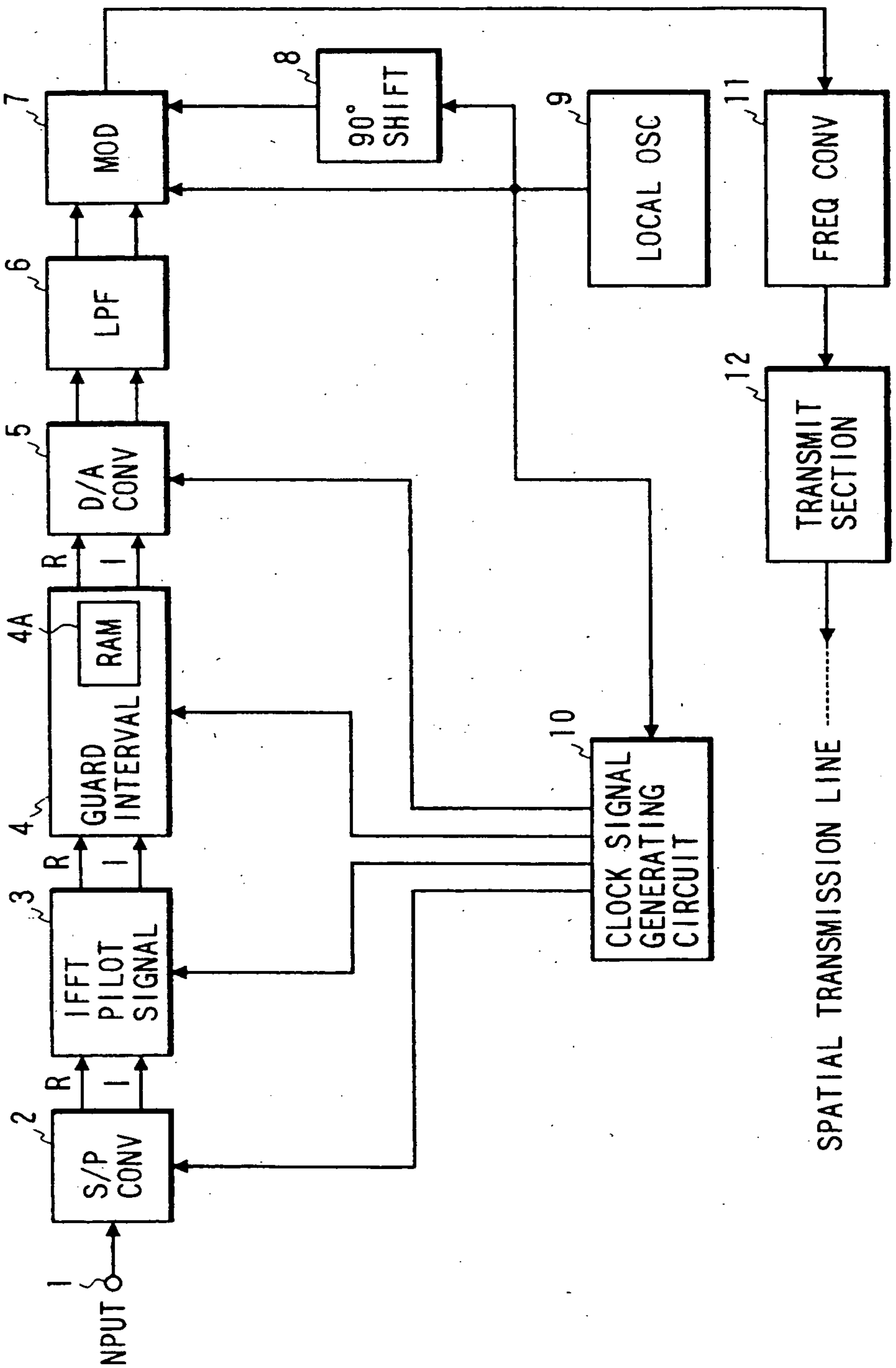


FIG. 3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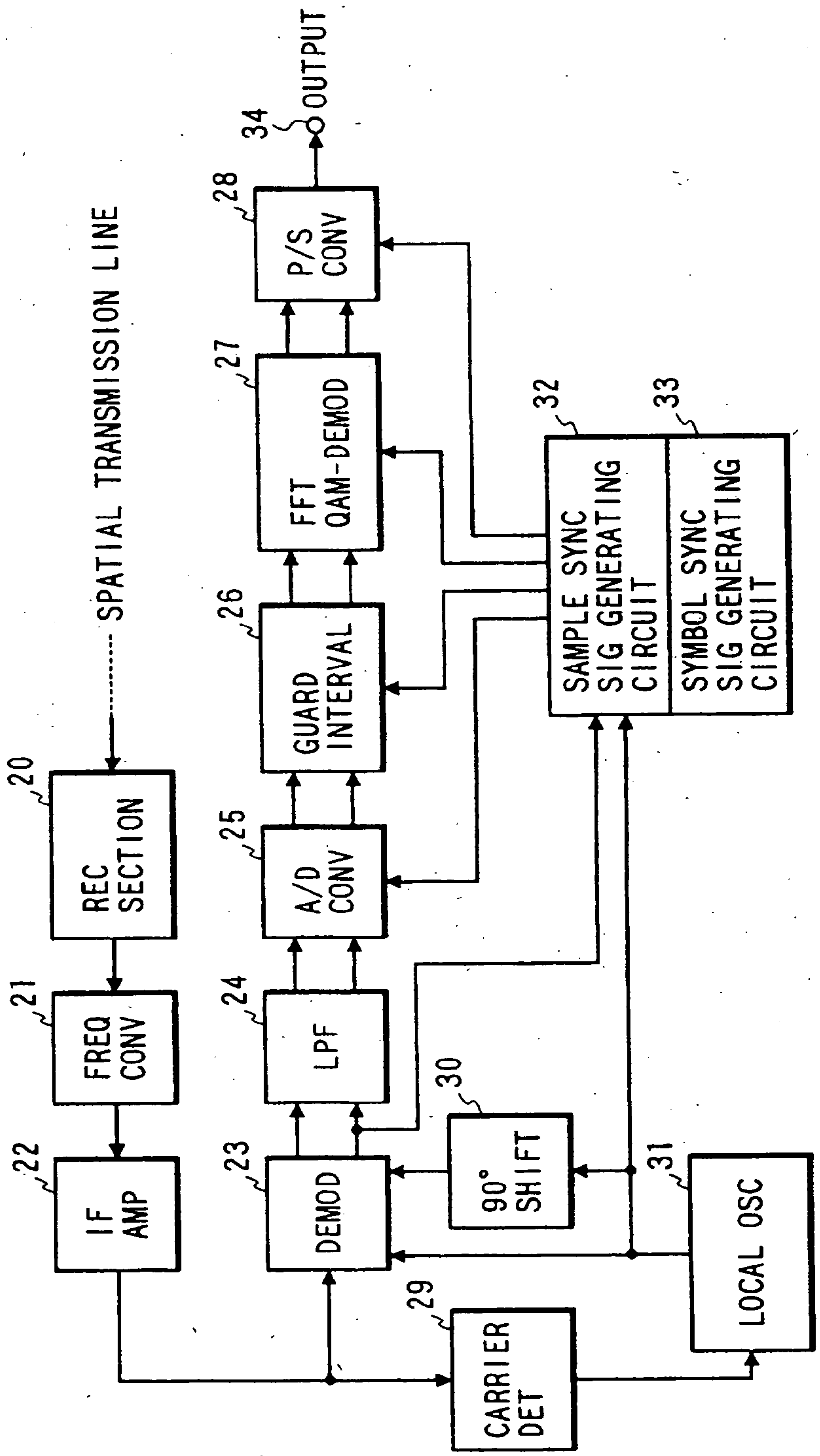
1
S/P CONV
2
IFFT PILOT SIGNAL
3
R
I
GUARD INTERVAL
4
RAM
4A
D/A CONV
5
LPF
6
MOD
7
90° SHIFT
8
LOCAL OSC
9
CLOCK SIGNAL GENERATING CIRCUIT
10
FREQ CONV
11
TRANSMIT SECTION
12
SPATIAL TRANSMISSION LINE

FIG. 5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REC SECTION
21
FREQ CONV
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IF AMP
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DEMOD
24
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27
FFT QAM-DEMOD
28
P/S CONV
34
OUTPUT
29
CARRIER DET
30
90° SHIFT
31
LOCAL OSC
32
SAMPLE SYNC SIG GENERATING CIRCUIT
33
SYMBOL SYNC SIG GENERATING CIRCUIT

FIG. 7

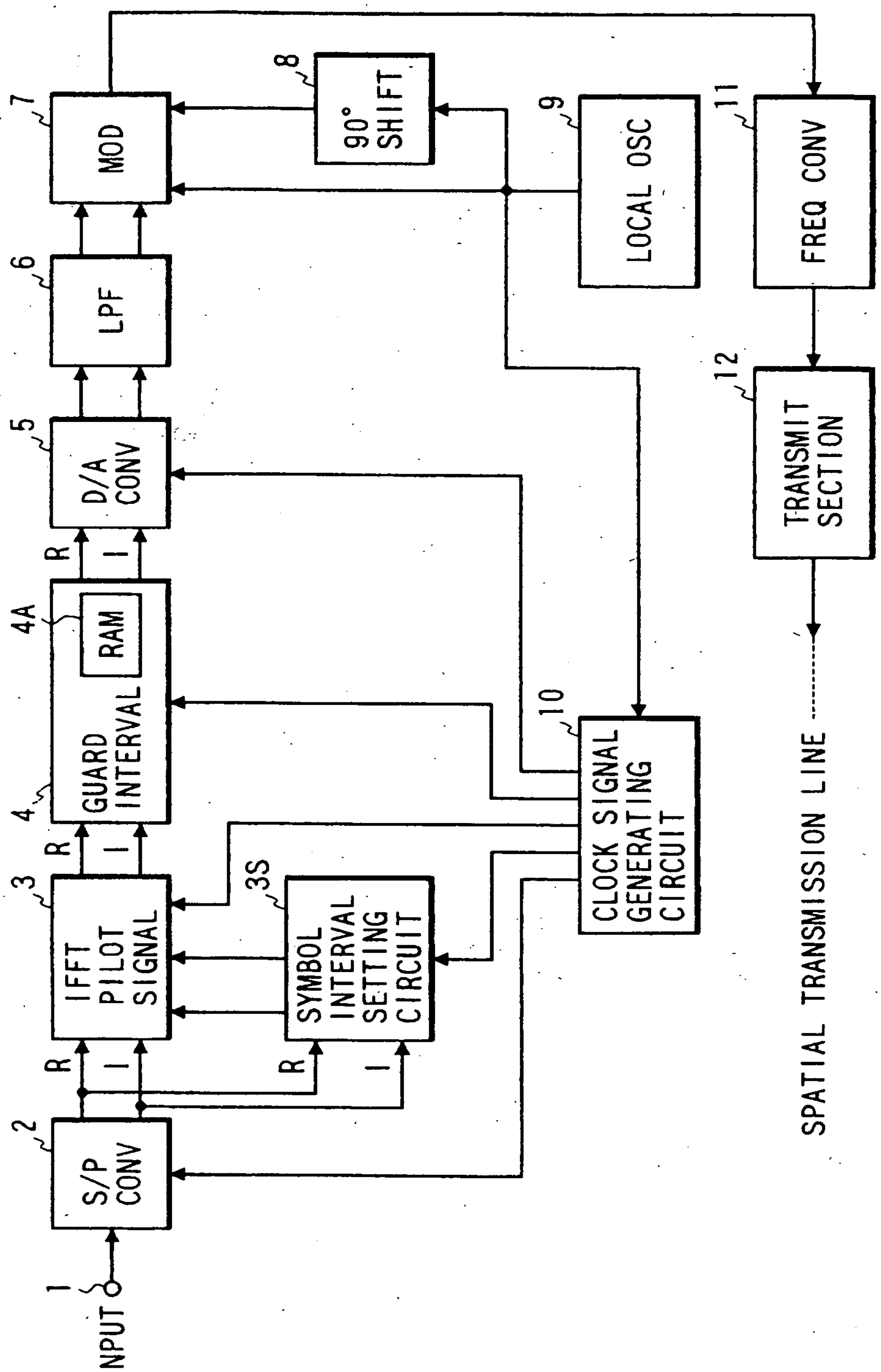
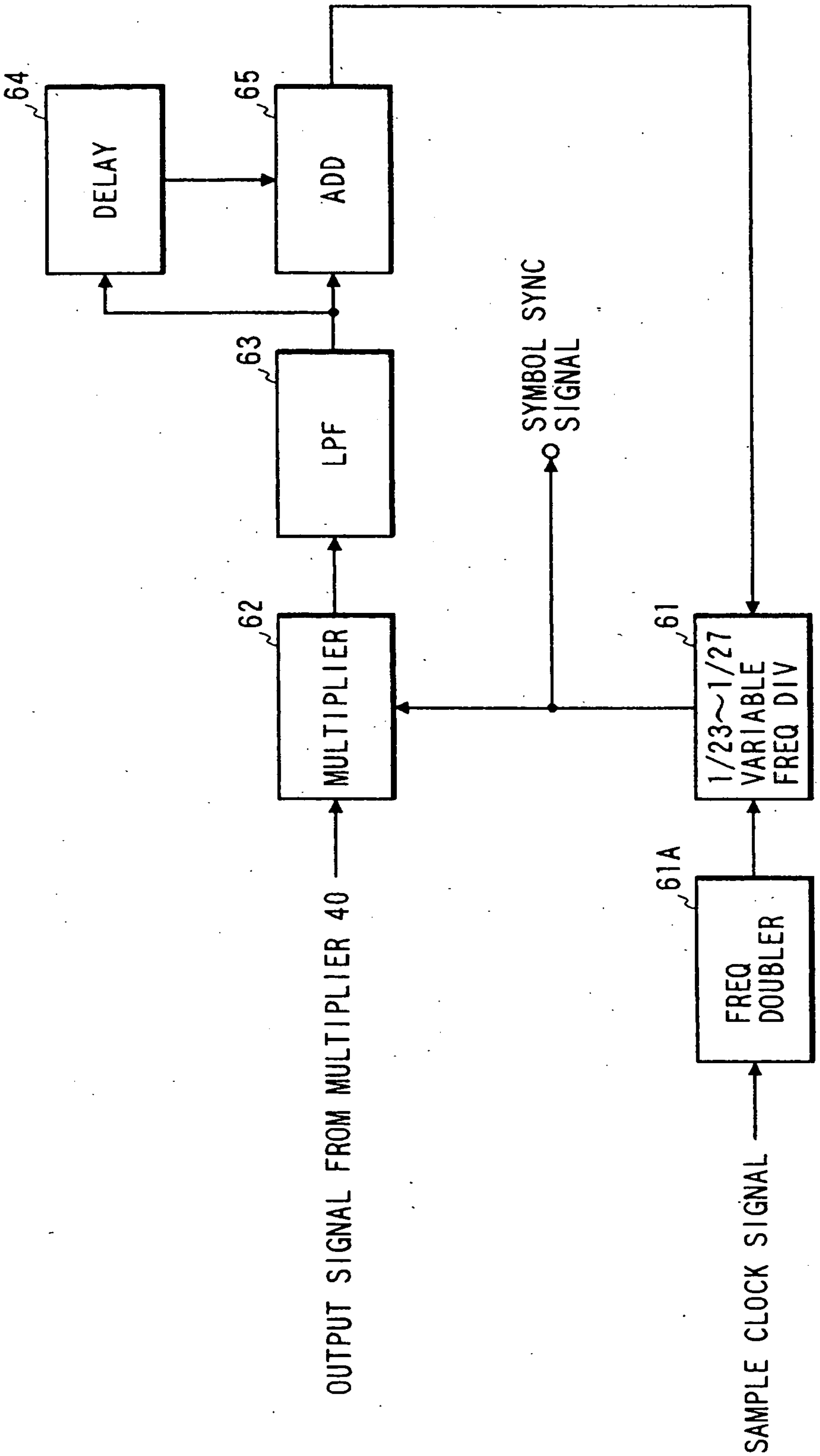

INPUT
1
S/P CONV
2
IFFT PILOT SIGNAL
3
R
I
SYMBOL INTERVAL SETTING CIRCUIT
3S
GUARD INTERVAL
4
RAM
4A
D/A CONV
5
LPF
6
MOD
7
90° SHIFT
8
LOCAL OSC
9
CLOCK SIGNAL GENERATING CIRCUIT
10
FREQ CONV
11
TRANSMIT SECTION
12
SPATIAL TRANSMISSION LINE

FIG. 9


33A
64
DELAY
65
ADD
63
LPF
62
MULTIPLIER
SYMBOL SYNC SIGNAL
61
1/23~1/27 VARIABLE FREQ DIV
61A
FREQ DOUBLER
OUTPUT SIGNAL FROM MULTIPLIER 40
SAMPLE CLOCK SIGNAL

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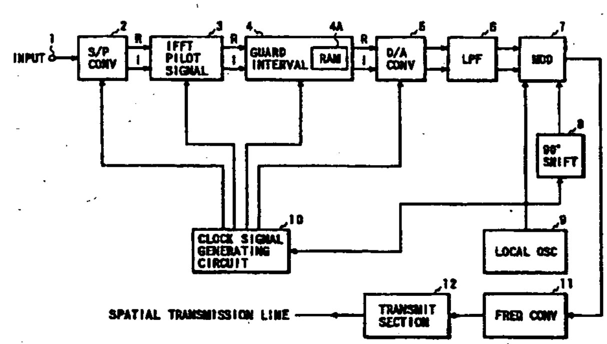
(54) OFDM transmitter and receiver

(57) A signal transmitting apparatus using orthogonal frequency division multiplexing includes an inverse fast Fourier transform circuit for converting a digital information signal into a first multi-value QAM modulation signal. A guard interval setting circuit is operative for periodically generating a guard interval signal equal to a time segment of the first multi-value QAM modulation signal, and inserting the guard interval signal into the first multi-value QAM modulation signal to convert the first multi-value QAM modulation signal into a second multi-value QAM modulation signal. A clock signal generating circuit is operative for generating a first clock signal which drives the inverse fast Fourier transform circuit, and generating a second clock signal which drive the guard interval setting circuit. The inverse fast Fourier transform circuit is operative for generating a pilot signal which corresponds to a given-order carrier, and adding the pilot signal to the first multi-value QAM modulation signal. The pilot signal has a predetermined frequency and an angle modulation component which remains constant over a plurality of symbol periods. The pilot signal corresponding to a given integer times its wavelength is present in a guard interval occupied by the guard interval signal in the second multi-value QAM modulation signal. The pilot signal is continuously present over the guard interval and another interval.

FIG. 3



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